

FUEL CELLS FOR THE TRANSPORTATION INDUSTRY: DEVELOPING A CREDIBLE DEMONSTRATION PROGRAM ON THE PATH TO COMMERCIALIZATION

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AC Transit, one of the largest bus-only urban transit operators in the United States, has initiated a demonstration program to evaluate fuel cell technology for the public transit industry. Critical to its success is an alliance with the University of California, Davis and the Department of Energy's National Renewable Energy Laboratory (NREL), to design and implement a comprehensive evaluation that will provide the international transit community with a repository of information to aid in the commercialization of the technology for transit applications. The evaluation will focus on maintenance and operational performance, life-cycle costs, safety, public education and acceptance, and employee training.

1. Introduction – the Need for Demonstration Programs

Fuel cell technology for automotive applications has made significant development strides in the last ten years, offering the promise and opportunity to replace the internal combustion engine with a clean, quiet, efficient, and environmentally sound alternative. Environmental benefits include the potential for zero-emissions in dense, urban neighborhoods; substantial reductions in noise levels with the use of quiet, electric drive systems; significant reductions in greenhouse gas emissions; and the potential use of renewable sources of energy – solar, wind, and hydropower – to produce hydrogen fuel.

The design of heavy-duty, fuel cell engines has been refined to the point that 40' urban transit buses, weighing in excess of 13,600 kg (30,000 pounds) are able to carry capacity loads (70 to 80 people) up grades in excess of 15%; travel at freeway speeds of up to 103 km/hr (65 mph); and maintain on-time scheduling demands with quick and efficient acceleration. While the technology is here to produce these kinds of operating characteristics, it still remains to be tested and developed for sustained levels of performance over daily duty cycles of up to 15 to 17 continuous hours (5,000 hours/year, 96,000 km/yr, or 60,000 miles/yr); longer distances between fueling, as far as 485 km (300 miles); durability over five to six years; and competitive capital and life cycle costs (\$300,000 USD for a comparable diesel bus and \$350,000 USD for a CNG bus). There also remain vast institutional and “cultural” differences between 20th Century diesel technology and 21st Century fuel cell technology, which will need to be addressed in the critical areas of education, training, safety, workplace environment, and building acceptance and support among employees.

Testing fuel cell technology and developing a realistic path toward commercialization requires a necessary transition from the confines of a test laboratory to the real-world environment of a heavy-duty urban transit operator. A well-managed demonstration program can serve to effectively bridge the gap between these two very distinctive cultures.

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2. Commercialization of Fuel Cells and the Role of Fleet Applications

Developing consumer preference for fuel cells as an alternative to the internal combustion engine (ICE) in light-duty vehicles, will require the pursuit of three very important objectives: 1) achieving comparable performance standards to an ICE; 2) realizing substantial reductions in cost to make fuel cell vehicles competitive in the market place; and 3) establishing a distributive fueling and maintenance infrastructure to accommodate extended travel distances. The timeline necessary to accomplish these objectives in the automotive industry may be at least 10 to 15 years, or longer, particularly given the high cost of fuel cells, limited onboard storage capacity of hydrogen fuel for small vehicles, and the lack of a decentralized fueling infrastructure.

The urban transit industry offers a very different scenario, providing an excellent opportunity to begin real-world testing relatively soon (as early as mid- or late-2004), enabling the fuel cell industry to introduce and educate large numbers of people (riders and non-riders alike) to the existing potential of fuel cell technology. Three important factors differentiate the demonstrative capabilities of light-duty and heavy-duty applications. Transit operators are better able to address onboard fuel storage because of the large size of their vehicles, fueling stations are centrally located and can easily accommodate a relatively restricted range of travel, and maintenance activities are almost always concentrated at a single facility.

To be sure, there still remain significant challenges, including those cited previously with respect to the vehicles, as well as the difficulty of managing fueling operations for a large fleet. Poetry in motion could not be better illustrated than by observing 200 forty-foot buses being refueled at near “break-neck” speeds, as they line up three wide and four to five blocks deep at an operating division’s doorstep, following the conclusion of evening peak-hour service. The reality is that with a large fleet of buses, each vehicle must be refueled within five to seven minutes, or operating costs would escalate prohibitively. Fueling gaseous hydrogen at similar speeds poses significant challenges.

Commercializing fuel cell technology for transit applications will not require a complete closure of the gap between diesel-powered buses and fuel cell buses. A more realistic objective is to narrow the gap, reducing costs and improving performance reliability, leading to an acceptable tradeoff of these factors in return for achieving critically important environmental benefits.

3. AC Transit as A Model Demonstration Site

What makes AC Transit a model demonstration site? In particular, how can AC Transit’s experience with fuel cells be compared to other fuel cell transit experiences and, more importantly, extrapolated to the industry as a whole?

AC Transit (District) is California’s third largest transit agency and the third largest bus-only operator in the United States. With a fleet of 779 buses, AC Transit carries 70.6 million passengers annually (236,000 passengers each weekday)^[1], serving 13 cities, including Berkeley and Oakland, in the East Bay region of the San Francisco Bay Area.

The District maintains a route structure of more than 150 lines, of which 36 operate between the East Bay and San Francisco via the San Francisco-Oakland Bay Bridge. Its fleet of buses is maintained at four operating depots and one Central Maintenance Facility.

The latter is devoted entirely to heavy-duty maintenance and repair, including the manufacture and repair of specialty parts, body fabrication and repair, body painting, rebuilding engines and transmissions, re-powering older buses with new engines, and maintaining a centralized parts inventory. The largest operating division has a fleet of approximately 250 buses, which is the optimal maximum size for a bus division. This compares favorably to much larger transit operators, like the RATP in Paris, France, which has a fleet of 4,000 buses and approximately 23 operating divisions, each with no more than 250 buses.

Service Characteristics	Values
Service Area Size	932 sq km (360 sq mi)
Service Area Population	1.5 million
Areas Served	13 cities and the unincorporated areas of two counties ⁴
Ridership	70.6 million boardings per year ^[1]
Ridership Growth	7% increase since 1999
Market Share	12% of all work trips in service area ^{5 [2]}
Lines (Routes)	150 (36 Transbay Lines to San Francisco)
Fleet Size	779 revenue vehicles
Employees	2,480 (1,410 drivers)
FY 2001/2002 Budget	\$244 million USD (Operating and Capital)

Table 1. AC Transit Service Characteristics

In late 1999, AC Transit had the opportunity to test the Xcellsis (now Ballard) ZEBus with its P4 prototype fuel cell engine. The District was impressed with its operating performance. The bus carried a standing load of passengers up 12% grades, ran at speeds in excess of 105 km/hr (65 mph), and easily handled boardings and alightings on its 51-Line between Oakland and Berkeley, which carries in excess of 20,000 riders per day. The District subsequently ran tests of the Mercedes-Benz NeBus in 2000 and received a very favorable reaction from riders and the public at large, because of its modern look and ultra-quiet, hub-motor drive system.



Figure 1. Xcellsis (Ballard) ZEBus



Figure 2. Mercedes-Benz NeBus

⁴ The cities of Alameda, Albany, Berkeley, El Cerrito, Emeryville, Fremont, Hayward, Newark, Oakland, Piedmont, Richmond, San Leandro, San Pablo, and service from these communities to San Francisco; and the western areas of Alameda and Contra-Costa Counties.

⁵ Compares with 9% for the San Francisco Bay Area^[2] and 5% nationally^[3]

Following its initial test of the ZEBus, AC Transit staff recognized the potential of fuel cells and the importance of taking a leadership role in developing the technology. The District's Board of Directors subsequently adopted a policy to pursue the development of the technology by seeking membership in the California Fuel Cell Partnership and applying for multiple grants to fund its program. In January 2000, AC Transit was invited to become a member of the Partnership, along with SunLine Transit Agency in Thousand Palms, California. Later, the Valley Transportation Authority in San Jose, California joined the Partnership as a third member transit agency.

From the beginning, AC Transit's role in pursuing the commercialization goals of the Partnership has been a commitment to prove the technology's worthiness in large fleet applications, operating a fleet of three or more buses under a variety of conditions common to most transit systems worldwide. The District is suitably qualified to be this test site for five primary reasons:

- A strong belief in the potential of this technology and the commitment of its entire staff, from board members to mechanics and drivers, to the demonstration program
- An industry reputation for a well-managed fleet, achieving performance standards of from 12,698 km (8,000 miles) between maintenance road calls (KBR) and 15,873 KBR (10,000 MBR). The industry standard is 6,349 KBR (4,000 MBR)
- A large fleet of 779 buses, with a division size of at least 240 buses
- An urban service area with lines that carry in excess of 20,000 passengers per day
- A diversity of terrain and services, including many hilly routes on grades in excess of 10%, freeway express routes, and service in densely populated areas

Additionally, AC Transit is committed to an extensive training and education program for its 2,480 employees. It has established the only California state-certified Heavy Duty Maintenance Training Program, where apprentices are enrolled in a four-year course leading to journeyman status. Over 180 mechanics participate, of which 90 are apprentices. Work has already begun to expand this program to include fuel cell technology. The District has also contracted with Schatz Energy Center at Humboldt State University to provide more than 25 ninety-minute "Introduction and Orientation" sessions for all of its employees. These sessions will cover a range of topics, including: hydrogen as the most prolific element on earth and its specific properties; the extensive use of hydrogen for industrial and research applications; safety concerns and dispelling myths associated with the Hindenberg and the Hydrogen bomb; and the District's fuel cell development program and the leadership role it will play in helping to commercialize the technology.

4. AC Transit's Fuel Cell Program

The main components of AC Transit's development program include the procurement of buses, construction of a fueling and maintenance center, development of additional fueling stations at other operating divisions, extensive training and education, public outreach, and a comprehensive evaluation program.

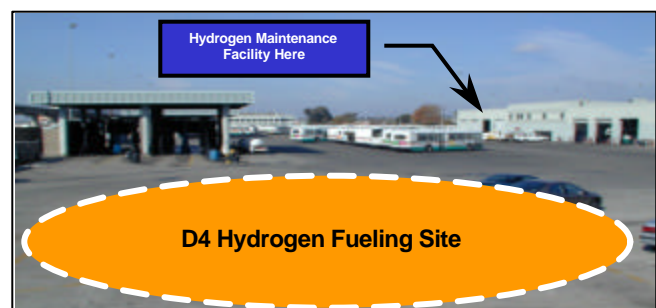


Figure 3. Division Maintenance and Fueling Site

Originally the District had planned for an initial procurement of as many as eight buses by the middle of 2003, with an expansion of its fleet to 12 buses as funding became available. Escalating costs and difficulties in finding a bus manufacturer have delayed the expected arrival of buses until mid- or late-2004 and restricted the number of vehicles the District will be able to purchase to no more than four or five. The original concept of utilizing 12 buses was to allocate three buses to each of four different kinds of routes – hilly routes, freeway express service, major urban trunklines, and neighborhood feeder lines. An effective evaluation can also be accomplished by a controlled rotation of four or five buses through all four duty cycles, measuring their performance against a control group of new diesel buses. Performance patterns will be evaluated to determine whether problems are a result of random failures or conditions unique to a particular duty cycle.



Figure 4. Future Hydrogen Maintenance Bays

Categories	Parameters (Criteria)
Maintenance	In-service reliability (kilometers/miles between maintenance roadcalls – KBR/MBR)
	Ease and speed of routine maintenance and major repairs
	Fueling speed
Operational Performance	Acceleration on local routes with heavy ridership (Schedule Adherence)
	Maximum speed on freeway express routes
	Power on hills and steep grades in excess of 10%
	Range of travel per day
	Smoothness of acceleration and braking
	Exterior and interior noise levels
Safety	Codes and standards (ISO Compatible)
	Work procedures
	Employee training
	Record of problems, violations, and accidents
Costs	Cost of new buses
	Life expectancy and cost of replacement parts
	Cost of hydrogen
	Life cycle costs of maintenance and operation
Employee and Public Acceptance	Employee acceptance
	Community exposure, awareness, and education
	Knowledge, acceptance, and support among riders and non-riders

Table 2. Fuel Cell Evaluation Parameters

5. Maintaining Continuity and Achieving Sustainability

AC Transit has received nearly \$14 million in grants from state, regional, and federal agencies, enabling it to launch an aggressive demonstration program.

Revenue Sources	Amount
State of California Traffic Congestion Relief Plan	\$8,000,000
California Air Resources Board	\$2,500,000
Bay Area Air Quality Management District	\$1,000,000
California Energy Commission	\$1,000,000
Federal Transit Fund	\$1,000,000
U. S. Department of Energy Clean Cities Program	\$300,000
AC Transit matching funds	\$1,100,000
TOTAL	\$14,900,000

Table 3. Revenue Sources for AC Transit's Fuel Cell Development Program

All but \$1.3 million came from state and local sources as a result of strong support from local officials, state legislators, and the California Governor's office. Mayors from all 13 cities in AC Transit's service area, and many environmental organizations, wrote letters of support to state and federal officials, strongly endorsing the District's proposal.

Although AC Transit has raised significant levels of funding, fuel cells are cutting edge technology and will require more financial resources to achieve the performance standards and production economies of a commercialized product. Existing grants and revenues will enable a credible program to begin, but sustaining a well-managed program over many years is critically important to realizing the ultimate goal of commercialization. Additional resources from federal agencies, including the U.S. Departments of Transportation and Energy, will be needed to support this endeavor and to ensure a continuity of effort and long-term sustainability.

Also key to this effort will be an extensive public outreach campaign, directed at educating the public on the advantages and benefits of hydrogen and fuel cells and generating strong community support. The District will pursue a number of key strategies, including:

- Utilizing the buses as "educational tools," while in revenue service. Each bus will be traveling billboards on the outside and information centers on the inside. The District will make every effort to circulate these buses throughout its entire service area, without compromising research and evaluation objectives
- Launching an extensive outreach effort, featuring educational videos, a speaker's bureau, cable T.V. commercials, and new editions of AC Transit's *Environmental Leadership Report*
- Developing an online educational curriculum for middle- and high-school students, working in conjunction with a new \$80 million regional space and science center in Oakland and local schools
- Converting a custom-made, electric mini-bus into a fuel cell bus for promotional and educational purposes at community events and schools

6. Bridging the “Cultures” of Diesel and Fuel Cells

Carefully documenting the two different cultures of diesel and fuel cells and defining the gap that separates the two, are essential steps to bridging that gap and establishing a credible and realistic path to commercialization. With these objectives in mind, AC Transit formed an alliance with the Institute of Transportation Studies at the University of California, Davis (UC Davis) and the Department of Energy’s National Renewable Energy Laboratory (NREL) in Golden, Colorado.

As partners, they have developed a detailed plan to identify measurable criteria, collect data, adopt standards of evaluation, conduct analyses and comparisons with other fuel cell demonstration projects, prepare and issue reports, and maintain a web-based repository of information to share with other organizations and the public. Joining this partnership, upon the award of a contract for the procurement of buses, will be the fuel cell engine and bus manufacturers, who will help shape the final evaluation plan and actively participate in its implementation. It is anticipated that the evaluation program will extend over a period of at least four years and longer.

7. Institutional Arrangement

A complex evaluation program must be well coordinated. AC Transit will organize and lead a working group consisting of NREL, UC Davis, the bus manufacturer, and the fuel cell engine manufacturer. These partners will meet regularly to coordinate activities, share collected and evaluated data, and determine the future evaluation process as the program moves forward. The defined roles for each member of the working group are as follows:

AC Transit – Will operate and maintain the fuel cell buses, allow data collection for the evaluation, and supervise the evaluation effort.

DOE/NREL – Will serve as the lead for the data collection and evaluation effort.

UC Davis – Will contribute fuel cell expertise, provide quick turnaround on-site support, and assist in data collection and analysis.

Battelle – Performing as a subcontractor to NREL, will assist in the data collection and analysis, and act as the lead in the reporting effort.

Bus and Fuel Cell Engine Manufacturers – Will provide vehicle and fuel cell support.

8. Establishing Criteria and Standards

The purpose of the evaluation program is to inform transit agencies, regulators, bus manufacturers, and fuel cell engine manufacturers about all relevant aspects of operating fuel cell buses in transit fleets. The program must, therefore, collect and analyze data not only on bus performance and reliability but also on fueling station operation, program costs, training, safety, and consumer acceptance. A description of the data to be collected is given below and in Table 4.

Type of Data	Frequency Recorded	Data Items
Descriptive Data		
Implementation Data	Start of data collection	Fleet characteristics, preparation for fuel cell program, roles of supporting organizations, etc.
Vehicle Operating Cycle	Start of data collection	Daily use of vehicles and speed versus time profile for vehicle routes.
Vehicle and Infrastructure System Descriptions	Start of data collection	Full specification of vehicle and fueling components.
Bus Performance		
Performance Data	Before bus operations	Maximum speed on grades, acceleration, noise.
Bus Operations		
Fuel Consumption	Each time a vehicle is fueled	Amount of fuel, hubodometer reading, date, fuel price
Engine Oil Consumption (diesel control buses only)	Each time oil is added or changed	Amount of oil, hubodometer reading, date, price per quart
Maintenance	For each work order	Type of maintenance, labor hours, date of repair, time out of service, hubodometer reading, parts replaced, parts cost, description of reported problem, description of repair performed
Safety Incidents	Each occurrence	Description of each accident or incident.
Cost Data		
Facility Infrastructure and Operating Costs	Start of data collection. Monitor operating costs throughout program.	System design, equipment, installation costs. Fuel and power costs.
Vehicle Capital Costs	Start of data collection	Vehicle capital cost for diesel control and fuel cell buses.
Fleet/Consumer/Public Acceptance		
Interview and Survey	Start of data collection and after several months of revenue service	Description of groups awareness and acceptance of AC Transit program, fuel cell buses, and hydrogen fuel.

Table 4. Data Collection Items

Descriptive data. The evaluation program will include significant descriptive accounts of AC Transit's implementation experience. This information will document the background work necessary to run a successful program using new transit technology.

Bus Performance. The buses will be tested to determine maximum speed on various grades, acceleration, and noise levels.

Bus Operations. A wide variety of data will be collected during bus operation. The data will include fuel consumption, scheduled and unscheduled maintenance records, and safety incidents.

Cost. The capital cost of the buses and fueling station infrastructure will be documented. Data will be collected on fueling station operations cost (fuel and power).

Fleet/Consumer/Public Acceptance. Interview and survey data will establish the response of AC Transit personnel, bus riders, and the public to the fuel cell bus program. Data will be taken before and after several months of revenue service to understand how the program experience modifies these responses.

9. Preparing a Baseline

The present standard for transit bus performance is the diesel bus. Transit agencies are fully aware of diesel bus costs, range, fueling times, speed and acceleration, and have designed their operations around these parameters. New technologies must fit well into the current transit systems, or they will be perceived as inferior choices. To properly evaluate a fuel cell bus fleet and especially the timeline to reach commercialization, fuel cell buses must be compared to the industry standard.

The evaluation program will select a fleet of diesel buses as a control sample. These buses will be chosen to match the fuel cell bus fleet in characteristics such as service years and size, and both fleets will operate on identical routes. All data collected for the fuel cell bus fleet will be collected for the diesel fleet except for minor differences such as oil changes and surveys or interviews.

Since fuel cell buses are an emerging technology, a strict comparison is not an appropriate measure of program success. Bus costs and reliability are expected to favor diesel buses. Through documenting the state-of-the-art for fuel cell buses, the evaluation program will enable the transit and fuel cell communities to determine what progress has been made since the past fuel cell bus demonstrations and, equally as important, to understand what additional progress must occur before fuel cell buses will be available commercially.

10. Data Collection, Analysis, and Reports

The commercialization process for fuel cell technology is expected to take five years or more. Initially, information will be collected for approximately 12 months of operation for each vehicle and will serve as the basis for the first stage of analysis. This baseline evaluation will determine the status of the technology and document the steps AC Transit took to implement the fuel cell buses into their operations, including the development of fueling infrastructure and maintenance facilities capable of maintaining hydrogen fueled buses. Analysis will include cost, maintenance, and operation of the fuel cell buses in comparison to conventional diesel buses. With the addition of the fuel cell engine and bus

manufacturer to the team, lessons learned from the early analysis will be used to further the development of the buses. Data collection will continue in the following years, showing the progress toward full commercialization.

There are three reports planned for the initial evaluation as follows:

- A two-page summary of vehicles and evaluation planned – this handout is intended to give an overview of AC Transit's program and describe the vehicle technology being evaluated
- An eight-page report – a brief summary of the implementation experience, including descriptions of the facilities and operation at the site
- Final Results Report – an executive summary style report based on all data evaluation and results to be completed after the data collection has been completed (after approximately 12 months of data have been collected on all vehicles at the site).

These reports will be made publicly available on the World Wide Web. As a part of this initial evaluation, the team will also explore the possibility of creating a web based repository for the data collected.

11. Closing the Gap

Although fuel cell buses have been in development for some time, detailed information on the evaluations have not been readily available. Until now, past evaluations were focused on demonstrations alone – at the conclusion of the projects, the buses were parked or returned to the manufacturer. This project focuses on taking the technology to the next step and beyond.

The planned evaluation will document the process of commercializing fuel cell buses, and help to educate other transit agencies considering this advanced technology. The results will lead to understanding the status of fuel cell technology, determining how the technology fits into a transit application, and identifying what needs to be accomplished to create a fully commercial product.

12. References

1. Alameda-Contra Costa Transit District: *AC Transit National Transit Database Report, Fiscal Year 2000-2001*, October 29, 2001. Oakland, California.
2. Metropolitan Transportation Commission: *Travel Forecast for SF Bay Area – 1998*. Oakland, California.
3. U.S. Department of Transportation, Federal Highway Administration: *Journey-To-Work Trends in the United States and its Major Metropolitan Areas 1960-1990*, 1994. Washington, D.C.

Curriculum Vitae

Jaimie Levin has been the Director of Marketing and Communications for AC Transit since April 1998. Previously, he published the *Lusk Review*, a real estate and development journal, in partnership with the University of Southern California's School of Planning and

Development. He also served from 1991 to 1996 as the Director of Marketing and Development for Solano Press Books, a California publisher specializing in professional references on land use and environmental law. He has a Masters of City Planning degree from the University of California – Berkeley, and a Bachelor of Arts degree in Urban Affairs from the University of Wisconsin – Green Bay.

Marshall Miller received his Ph.D. from the University of Pennsylvania in Physics. After postdoctoral work at the University of Chicago, he accepted a joint position with the University of California, Davis and the Union of Concerned Scientists studying technical and policy aspects of fuel cell systems for vehicles. He currently runs the Hybrid Vehicle Propulsion Systems Laboratory at the University of California, Davis where he studies advanced battery, ultracapacitor, and fuel cell technology. He is also the Director of the Hydrogen Bus Technology Validation Program which will operate hydrogen/natural gas mixture buses at the Unitrans transit agency in Davis.

Leslie Eudy has been a Project Leader at the National Renewable Energy Laboratory since June of 1997. Her work at NREL involves managing evaluations of alternative fuel and advanced technology heavy-duty vehicles. She came to NREL from ManTech Environmental Technology, Inc., where she managed the emissions testing program of light-duty alternative fuel vehicle (AFV) fleets for NREL. Leslie has a degree in Geology from the University of North Carolina.